Answer all five questions (in English, Finnish, or Swedish). Using a calculator is allowed, but all memory must be cleared!

1. Describe the cascaded control system of DC motors. Draw also the block diagram of the control system, label the signals in the diagram, and describe the tasks of the blocks.

2. Answer briefly to the following questions:
   (a) Why a speed reduction gear is often used in electric drives?
   (b) Why three-phase machines are preferred to single-phase AC machines?
   (c) How the physical size of the motor approximately depends on the rated values of the motor?

3. A surface-mounted permanent-magnet synchronous motor is used to start a mechanical load. The total moment of inertia is 0.4 kgm^2 and the load torque is constant 10 Nm. The motor is fed from an inverter using the control principle $i_\mathrm{d} = 0$. The rated power of the motor is 3.75 kW and the rated speed is 2 400 r/min. The current limit of the inverter has been set to twice the rated current ot the motor. How long does it take to accelerate the motor and its connected mechanical load from zero to the speed of 2 000 r/min?

4. A DC motor with a separately excited field winding is considered. The rated armature voltage is $U_\mathrm{N} = 500$ V, rated torque $T_\mathrm{N} = 220$ Nm, rated speed $n_\mathrm{N} = 1\,600$ r/min, and maximum speed $n_\mathrm{max} = 3\,200$ r/min. The losses are omitted.
   (a) The flux factor k_f is kept constant at its rated value. When the armature voltage is varied from 0 to U_N, the speed varies from 0 to n_N. Determine the rated armature current I_N.
   (b) A load is to be driven in the speed range from n_N to n_max by weakening the flux factor while the armature voltage is kept constant at U_N. Determine the torque available at maximum speed, if the rated armature current I_N is not exceeded.
   (c) Sketch the armature voltage U_a, flux factor k_f, torque T_M, and mechanical power P_M as a function of the speed, when the armature current is kept at I_N. Clearly label axes of your graph.

Please turn the page for Problem 5.

5. Consider an inverter-fed permanent-magnet synchronous motor, whose rated speed is 2 400 r/min and number of pole pairs is $p = 4$. The motor parameters are determined using the following three tests:

   (a) The rotor speed is zero. The constant current vector $\underline{i}_\mathrm{s} = i_\mathrm{d} = 15.0$ A is fed into the stator winding by means of closed-loop current control. In this steady-state condition, the voltage vector is $\underline{u}_\mathrm{s} = u_\mathrm{d} = 7.5$ V according to the inverter control algorithm. Determine the stator resistance R_s.

   (b) The rotor speed is zero also in this test. The inverter produces a pulsating sinusoidal voltage into the d-axis, while the q-axis voltage is kept zero, i.e.,

   $$\underline{u}_\mathrm{s}(t) = u_\mathrm{d}(t) = U \sin(\omega_\mathrm{c} t)$$

   where the amplitude is $U = 50$ V and the angular frequency is $\omega_\mathrm{c} = 2\pi \cdot 200$ rad/s. The measured d-axis current response is

   $$\underline{i}_\mathrm{s}(t) = i_\mathrm{d}(t) = I \sin(\omega_\mathrm{c} t + \phi)$$

   where the amplitude is $I = 8$ A and the phase is approximately $\phi = -\pi/2$. Determine the stator inductance L_s (assume $R_\mathrm{s} = 0$ due to the high frequency). What is the torque produced by the motor during this test?

   (c) The motor is controlled to rotate at the speed of 1 200 r/min in a no-load condition. The line-to-line rms voltage of 190.8 V is supplied by the inverter. Determine the PM flux linkage ψ_f.